Optical Metrology and Scanning Electron Microscopy of Paper Damage by Writing

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BIOGRAPHY

Pierre Vernhes is a PhD student at the French Institute of Paper Making and Printing (EFPG in Grenoble). He is currently working on paper properties and the relationship between paper structure and optical properties. He has also worked in the field of art restoration at the ICN in Amsterdam where he researched paper lightfastness.

ABSTRACT

Although nowadays computer word processors are ubiquitous, mankind is still not ready to give up on handwriting. An improved understanding of the properties of paper, ink and pencil is needed to develop new writing products. There is a need to improve the paper quality to facilitate writing since poor gliding of the pen or pencil tip can result in a disappointing tracing. The aim of this study was to characterize the damage induced on paper by pens and pencils. A new optical metrology device was tested to investigate the paper surface topography following pen and pencil strokes on different types of paper applied with various pressures. Paper roughness and surface deformability were found to be key parameters in reaching the best compromise.

KEYWORDS

optical metrology, environmental scanning electron microscopy, topography, handwriting, paper, pencil

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INTRODUCTION

Although nowadays computer word processors are ubiquitous, mankind is still not ready to give up on handwriting. An improved understanding of the properties of paper, ink and pencil is needed to develop new writing products. There is a need to improve the paper quality to facilitate writing since poor gliding of the pen or pencil tip can result in a disappointing tracing. So handwriting is a compromise between the paper characteristics, the ink properties and the way it is deposited [1].

The aim of this study was to characterize the damage induced on paper by writing with a pen or pencil. A new metrology device was chosen to characterize the paper surface topography. The 'focus-variation' system has the benefit of being able to reconstruct the topography of surfaces presenting steep flanks and high illumination contrast. It is an ISO 25178 approved method for surface measurement [2] and allows measurements over large areas with a density of 2 to 25 million measurement points and a vertical resolution up to 10 nm. It provides a true colour image that reproduces surface topography in a visual context; for the study of handwriting, this can be especially useful in characterising the ink transfer and understanding the interaction of paper and ink.

MATERIALS AND METHODS

Papers, Pens and Writing

Handwriting experiments were done with a BIC liquid ink roll pen and an HB carbon pencil on coated and non-coated papers. The uncoated paper was standard office paper (weight 90 g m^{-2}); the coated paper (120 g m^{-2}) had a coating layer mainly composed of calcium carbonate and clay.

To analyze the damage induced by the writing on the paper sheets different pressure were applied. The exact pressure applied was hard to quantify because of the lack of information on the contact area between the pen or pencil and the paper during the writing. Nevertheless, the low, medium and high pressures corresponded approximately to a weight on the pen support of 250, 500 and 750 g, respectively.

Scanning Electron Microscopy

Electron microscopy observations were performed using an FEI Quanta 200 ESEM environmental scanning electron microscope at a pressure of 133 Pa and an accelerating voltage of 12.5 kV. Images were acquired with a large-field detector which collected secondary electrons. Tilting of the support stage was used in order to improve the visualization of the surface topography.

Topographical Measurements

The topographical study was performed with the Infinite Focus metrology system developed by Alicona. Infinite Focus is an optical 3D measurement device that acquires a dataset at a high depth of focus similar to the SEM.

The main component of this optical metrology instrument is a precision optic consisting of various lens systems. It can be equipped with different objectives allowing measurements with different resolutions. With a beam

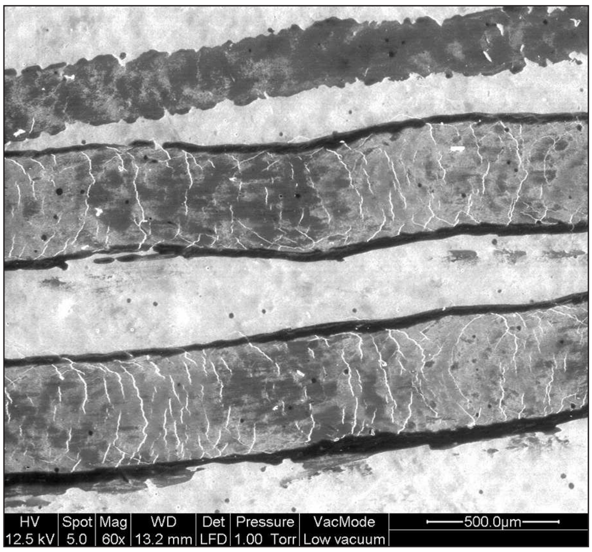


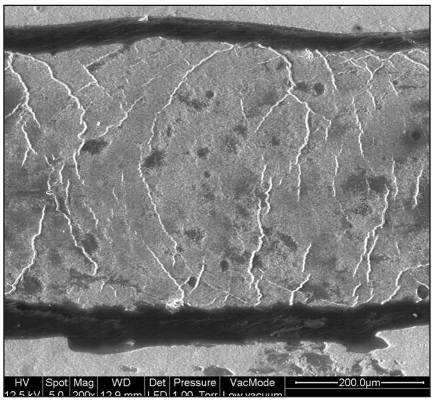
Figure 1a:
Environmental scanning electron micrograph of pen strokes on coated paper. A low pressure stroke is seen at the top, a medium pressure stroke in the middle and a high pressure stroke is shown at the bottom. Tilt: 0°.

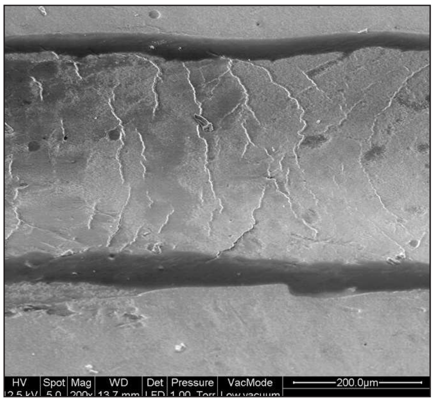
splitting mirror, light emerging from a white light source is inserted into the optical path of the system and focused onto the specimen via the objective. Depending on the topography of the specimen, the light is reflected into several directions as soon as it hits the specimen. All rays emerging from the specimen and hitting the objective are bundled in the optics and gathered by a light sensitive sensor behind the beam splitting mirror. Due to the small depth of field of the optics only small regions of the object are sharply imaged. To allow a complete detection of the surface with full depth of field, the precision optic is moved vertically along the optical axis. A sensor captures a series of 2D datasets during this scanning process. This means that each region of the object is sharply focused. After the scanning process, the 2D datasets are evaluated to generate 3D information as well as an image with full depth of field. This is achieved by analyzing the variation of focus along the vertical axis. Once all height measurements are determined, an image with full depth of field is computed. A key characteristic of the system is that it does not only deliver topographical information but also an optical colour image of the surface which is perfectly registered to the height data.

The technology on which the system is based has recently been included into ISO standards classifying different methods for surface texture extraction [2]. In contrast to many other optical devices InfiniteFocus is capable of measuring surfaces with steep flanks of 80° and more [3]. This feature is especially important for paper damage analysis, where deep holes or fractures can be analysed. The vertical resolution can be as low 10 nm making the instrument ideal for measurements in the submicron range. Recent studies have shown very accurate results for roughness [4] and form measurements [5].

RESULTS

Figure 1a shows an ESEM image of three pen strokes on coated paper. At the top of this image the stroke was produced by low applied pressure. The printing is quite regular and





Figures 1b and 1c:
Environmental scanning electron micrographs of pen strokes on coated paper. (b) High pressure stroke. Tilt: 0°. (c) High pressure stroke. Tilt: 37°.

homogeneous even if it was possible to determine an indent aspect. For the medium and the highest pressures, the strokes were larger and heterogeneous. The dark grey levels at the edges of the strokes indicate a superabundance of ink.

Focusing on the high pressure stroke (Figure 1b), it was possible to say that the mechanical action due to the friction between the pen roll and the paper produced some cracks. Furthermore, when tilting the sample, a surface deformation was observed too (Figure 1c). The ink bulges were in relief whereas the middle of the stroke was depressed.

For the non-coated paper, the pen strokes seemed to have quite good quality and the paper did not seem to be damaged (Figure 2a). However, a more careful observation, especially for the high pressure stroke (Figure 2b), showed that the paper surface was damaged. The additional contrast obtained by the tilting of the sample revealed the presence of a furrow along the middle of the stroke (Figure 2c).

Figure 3 shows the results obtained with the optical metrology system. The magnification chosen was ×10 which gave a pixel size of 800 nm. We can see that the main part of the ink was situated at the edge of the line. As a matter of fact the roll of the pen carried the ink. Nevertheless, due to the pressure field created at the tip, the ink moved in an orthogonal direction compared to the tip movement. As expected, the shape and the depth of the two lines were quite different. Let's be reminded that the larger line corresponds to the maximum of pressure applied on the pen.

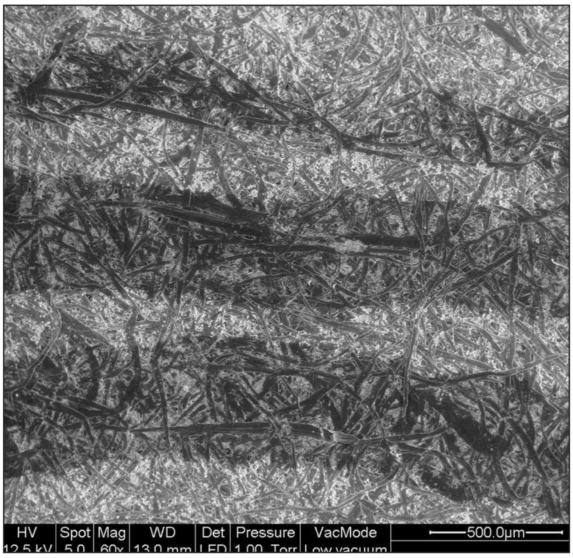
Figure 4 is a view of the profile of the BIC pen stroke on the coated paper in the high-pressure case. As seen in Figure 3 the ink is mainly situated on each sides of the stroke. That is why we can see a small border in the profile for l = 75 µm and l = 425 µm.

The uncoated paper was basic handwriting paper having a high roughness index (root mean square = 5.5 µm). Hence the effect of the pen on the paper surface was less visible than in the case of the coated surface. As a result, in Figure 3b the top line is not distinguishable on the colour topography map.

The specificity of coated paper in general is to have good smoothness. But on the other hand the layer on top of the paper is fragile and is not deformable. That is why the effect of the writing on this paper grade is much more important than for the uncoated paper.

CONCLUSIONS

The optimization of the trio paper, ink and applied pressure on the pencil is of the greatest importance in order to develop new prod-



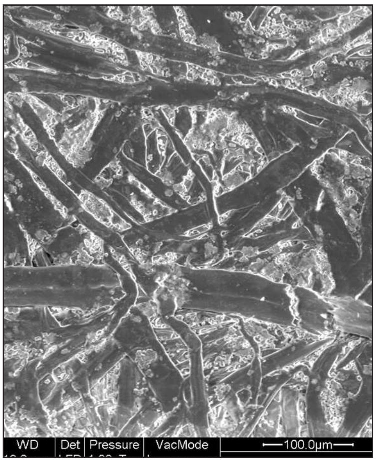


Figure 2:
(a) ESEM image of pen strokes on non-coated paper. Low pressure stroke at top, high pressure at the bottom. The tilt was 0°. (b) Detail of high-pressure stroke with tilt = 0°. (c) Detail of high-pressure stroke with tilt = 37°.

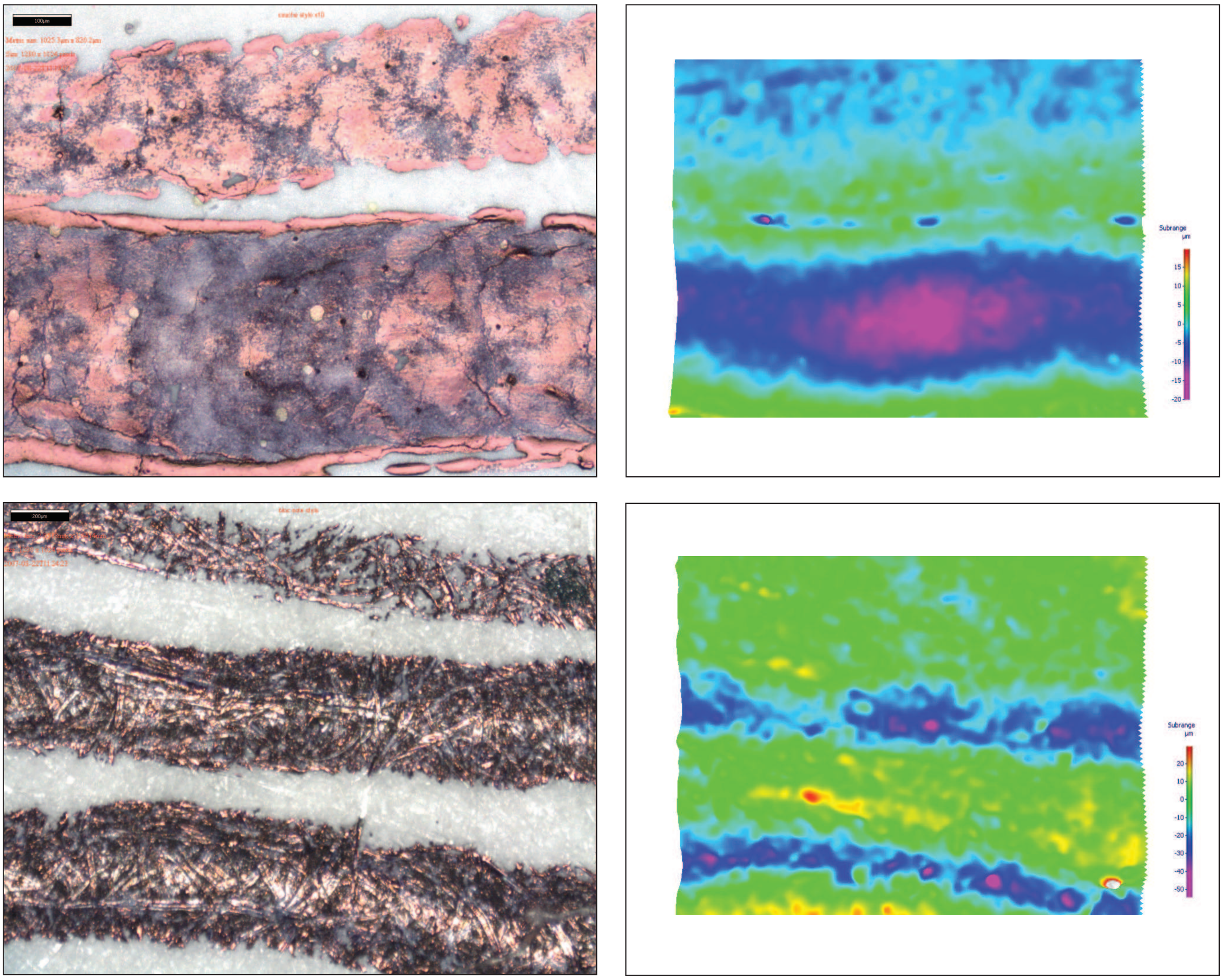


Figure 3:
Optical and topographical images of pen strokes on paper. (a) Coated paper optical image with (b) topographical data. (c) Uncoated paper optical image with (d) topographical data. HFW = 800 μm.

ucts which achieve the highest customer satisfaction in handwriting. This study highlights the necessity to combine the techniques of observation and topographical characterization.

The roughness due to the mechanical action of pencil on paper is as evident on paper with high roughness. For scanning electron microscope imaging, the use of tilt is obligatory. In our case, and especially for the uncoated paper, a knowledge of the topography is essential because of the paper roughness which masks the track of the roll.

The complementarity of ESEM and optical microscopy coupled with a topographic three-dimensional treatment, allow the determination of the resistance of the paper to the pencil roll by the measurement of the frequency and the depth of cracks.

The consequences of this of this study could be to adjust the composition of the coated layer to the quality of the handwriting by optimizing the size of the pencil roll. Another example could be to optimize the carbon pen composition to optimize the writing and the deposition ability of the carbon.

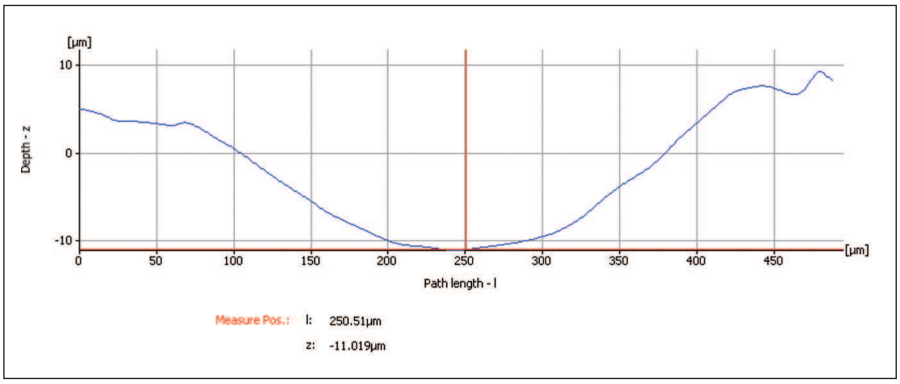


Figure 4:
Cross-section profile of the pen stroke on coated paper (high pressure case). The width of the stroke is around 400 μm and its depth is around 12 μm.

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